# Elastic Modulus Maps of Soft, Rubber-like Gels and Tissues from AFM Nanoindentation

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Although the atomic force microscope (AFM) has found wide applicability as an imaging and nanoindentation tool for measuring local elastic properties of biological tissues and other soft, elastic materials, its high-throughput potential is unrealized due to the lack of a robust, automated technique to process large collections of qualitatively diverse indentation data. By combining the raster-scanning capabilities of a commercial AFM and an automated algorithm based on Hertzian and adhesive contact mechanics models, we show that high-resolution elastic modulus maps of soft, elastic materials can be generated. The approach addresses many of the issues that have hindered automation, particularly the wide variability in force-displacement behavior when probing soft, inhomogeneous samples and eliminates most of the need for subjective user input by utilizing optimization search strategies. The algorithm evaluates the level of adhesive interactions and chooses between Hertzian models and the various adhesive contact mechanics formulations. We demonstrated the accuracy of the method by indenting poly(vinyl alcohol) gels of known composition and tuned mechanical properties and verified robustness by automatically fitting large datasets from the indentation of native as well as tissue-engineered cartilage. Cartilage is a highly inhomogeneous tissue that behaves as a stiff elastic polymer to sudden impact loading, but shows some slow inelastic deformation with sustained loads. It has a tough but compliant load-bearing surface the characteristics of which depend on the integrity of the collagen network and on the retention within it of charged bottle-brush shaped aggrecan molecules. The proposed approach promises to make high resolution mapping of elastic properties of soft, inhomogeneous samples widely available.